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Experiments Out of the Solar System

Ecliptic Plane: An Introduction  
to the Execliptic Mission\*

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I. Introduction

The dramatic step made possible by direct measurements in space with satellites and probes during the past 18 years has totally altered our concepts of the Sun, the interplanetary medium, and their influences upon Earth. This has been achieved with observations confined solely to the vicinity of the equatorial plane of the solar system. From these two-dimensional investigations we have made dubious attempts to extrapolate our knowledge to deduce what the Sun and space in the solar system is like in three-dimensions. However, the solar, interplanetary and galactic phenomena discovered in these years have raised many urgent scientific questions which can only be answered by direct observations and experiments far out of the ecliptic plane and over the solar pole to achieve a "global" concept of the Sun, the interplanetary medium, and their relationship to Earth and the boundary of the heliosphere with the interstellar medium. We have been faced for many years with this age-old problem which occurs often in science, namely, the extrapolation of physical phenomena from two-dimensions to deduce phenomena in three-dimensions. The uniqueness and importance of

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a scientific mission which can directly achieve this global study and the recognition of its potential for discovery has been clear for many years. In describing such an exploratory mission, it is not unfair to make a comparison between the importance of Man's exploration of the spherical surface of the Earth, and an ex-ecliptic mission, which is qualitatively similar in its conceptual and practical consequences for space science to the impact of the full exploration of Earth on Man's intellectual advancements.

If a mission out of the ecliptic is so vital to the advancement of science then why has it not become a reality by now since the technology for its accomplishment has been with us for several years, and Pioneers 10 and 11 have demonstrated that a Jovian gravity-assist to drive a probe out of the ecliptic is safe? Among the reasons appears to be the broad, interdisciplinary character of the most important investigations on the mission which, on the one hand, represents the greatest strength of the mission, but, on the other hand, becomes a source of weakness for marshalling the sources and the support of the scientific community, or even leadership within the federal agencies where the missions must successfully compete with other important types of space missions. Since the late 1950's an out of the ecliptic mission has been under discussion.<sup>1</sup> Now, hopefully, it is a mission whose time has come since it has recently elicited support from a wide segment of the scientific community on the basis of its uniqueness and importance for science and the applications of science to our understanding of the Sun and its influence upon Earth. Furthermore, as has been the case for the space program to date in the equatorial plane, out-of-the-ecliptic observations are almost certain to yield important, unanticipated discoveries. We can best describe the quality of the mission objectives as exploratory and interdisciplinary and, therefore, the investigations must be designed to encompass the unexpected.

The purpose of this note is to summarize the most likely alternatives for carrying out a mission to achieve these broad scientific goals and to illustrate with specific examples drawn

from charged particle astronomy, interplanetary and solar physics some of the experiments and observations which may be carried out. It is not within the scope of this note to describe in detail the many exciting scientific challenges opened by the mission, but the reader easily will perceive this wide range of possible investigations, many of which are discussed in the Proceedings of this Symposium<sup>2</sup> or outlined by Page.<sup>3</sup> As a basis for discussion of the regions of the Sun and interplanetary space which may be explored by exoecliptic missions I have prepared in Figure 1 a schematic representation of the main solar latitude zones of highest interest and their possible interfaces with the interplanetary medium. In the following discussion we will summarize some of the alternative missions which reach into these regions of space and the constraints they place upon experiments. As a secondary objective we shall also describe the opportunities which some of these missions provide for unique studies of the magnetosphere of Jupiter since, for the most likely mission choices, Jupiter becomes the "gateway" to space out of the ecliptic.

## II. Ten Ways to Get There

Table 1 is a summary of the most outstanding mission alternatives. There is a long history of successive proposals for these missions based primarily on available launch vehicle technology, hence some of the alternatives presented in Table 1 now are only of historical interest. Basically, the mission options are dependent on launch vehicle capabilities. Direct ballistic injection at  $\sim 1$  a.u. (option 7 and 8) even under optimum conditions will take a spacecraft only to  $\sim 37^\circ$  heliographic latitude. The addition of solar electric propulsion (SEP) makes it possible to achieve a spacecraft trajectory oscillating in latitude at 1 a.u., and synchronous with Earth thus scanning over a north-south latitude range that reaches a limit of  $\pm \leq 60^\circ$  within 2.7 years, under maximum launch capabilities (option 9, for details see reference 4 and 5). The trajectory plotted in a plane at 1 a.u. is shown in Figure 2. This type

of latitude scanning spacecraft, which must be triaxially stabilized would place a strong emphasis on extending present solar observations being made at Earth to stereoscopic viewing of these solar phenomena.<sup>4</sup> The rate of technical development of solar electric propulsion, however, is such that no possibility exists for considering this option in the early 1980's. Furthermore, from Figure 1 see that all of the direct injection missions discussed above do not allow observations in situ beyond the zones of solar activity and leave open all questions which could only be answered by attaining higher solar latitudes. As will be shown below, the polar cap-to-polar cap passes of Jupiter swingby missions will achieve the latitude scans of the SEP missions, although for a shorter interval of the solar cycle.

The alternative to direct injection is a gravity assist by Jupiter, i. e. by a Jupiter swingby (JSB) -- a technique first proven by Pioneer-10 to achieve a solar system escape trajectory.<sup>6</sup> This technique makes it possible to achieve solar polar cap passes with maximum latitudes depending on the launch constraints (options 1 - 6). Among those options that achieve polar cap passes of  $\geq \pm 80^\circ$ , options 1, 2, 3 and 6, offer the greatest potential for achieving our stated prime objectives of exploration and discovery. Option 6 enables a single spacecraft to reach  $\sim 79^\circ$  solar latitude with an Atlas/Centaur vehicle by requiring an Earth swingby as shown in Figure 3. However, in addition to the increased time to reach solar maximum latitude (1.7 years longer), this mission suffers further from reduced reliability because it requires an additional spacecraft propulsion subsystem to undertake two additional and critical spacecraft maneuvers as described in Figure 3. We focus on the most fruitful of all the JSB options, hopefully the most likely to be adopted, namely a dual spacecraft launch to Jupiter (options 1 or 2) which will result in spacecrafts over both solar polar caps simultaneously with trajectories as shown in Figure 4 passing from pole-to-pole in opposition. We refer to this type of mission as the tandem Jupiter swingby (TJSB).

### III. The Tandem Jupiter Swingby Mission

In Figure 4 we have identified the two spacecraft as A and B and have shown their trajectories from Jupiter swing-by until after their respective pole-to-pole passes at the Sun, all as a function of time. Although this example<sup>7</sup> is for option 2 in Table 1, the trajectories for option 1 will be similar. From the point of view of scientific investigations in different disciplines, e.g. solar physics, interplanetary plasma and magnetic field, the magnetosphere of Jupiter, cosmic rays, etc., the mission is logically to be divided into five phases identified by portions of the spacecraft trajectories. These are: (I) from Earth to Jupiter, (II) through the Jovian magnetosphere, (III) out-of-the-ecliptic simultaneously in the northern and southern hemispheres over the radial range  $\sim 1.5 - 5$  a.u., (IV) over the solar pole, and pole-to-pole transits of the two spacecrafts, and (V) post solar pole trajectories. In each phase there are some prime mission goals for one or more of the scientific investigations. In the following discussion we take the reader on a "guided tour" through these five phases of the TJSB missions using illustrative scientific investigations which will lead to discovery or the answer to old questions. Although it is not possible to discuss in this note all the important scientific objectives of each phase, these trajectories provide a rich source of new investigations with each phase of the mission possessing its own set of unique scientific objectives.

#### Phase (I): Earth to Jupiter

The two spacecraft travel near the ecliptic plane with a radial-spatial separation of order  $10^6$  kilometers and with simultaneous transmission of data. This separation makes it possible for us to undertake a new family of studies, since never before have spacecraft been so separated for a long period of time free from the influence of a nearby planet and never before have we had the opportunity to do correlative studies between closely spaced observation points over a large radial range. For example we may undertake:

- a) the study of charged particle-magnetic field interactions, especially for very low energy nuclear particles in the range 0.1 to 1 MeV. This spacecraft separation distance becomes comparable to the correlation length of the interplanetary magnetic field and to the scattering scale size of the particles.<sup>8</sup>
- b) the study of the modes of propagation and interaction with magnetic fields in interplanetary space of the electrons which have been recently found to be escaping from Jupiter.<sup>9-11</sup>
- c) measurements of the interplanetary acceleration of protons<sup>12</sup> and electrons in the regions surrounding blast waves from the sun.<sup>13</sup> It will also become possible to investigate in detail the forward-backward moving shocks which are now observed to be associated with so-called "interplanetary active regions".<sup>14</sup> These active regions and shocks are also associated with enhanced fluxes of ~ 1 MeV protons.<sup>15</sup>

This phase of the mission corresponds to an interplanetary version of the smaller scale Mother-Daughter satellite combination devoted to magnetospheric studies in the period 1977-1980. No other interplanetary mission studies of the above type have been made, or are contemplated in the foreseeable future.

#### Phase (II): Jovian magnetospheric studies

Since for operational reasons the two spacecrafts in opposite hemispheres will have times of closest approach 2 to 3 days apart, we obtain a unique and valuable separation of the two spacecrafts in the Jovian magnetosphere capable of attacking problems that could not be investigated by the Pioneer 10-11 spacecraft, the Mariner-Jupiter-Saturn spacecraft, or even a single Jupiter orbiter spacecraft. In Figure 5 we display a meridional plane projection

of the trajectories of the two spacecraft A and B. Figure 6 is a projection of the two spacecraft trajectories on the ecliptic plane. For comparison the Pioneer-11 encounter trajectory to Saturn is shown. At the time of closest approach for spacecraft A (position 1), spacecraft B is at a distance of  $\sim 50 R_J$  and when spacecraft B is at closest approach (position 10) spacecraft A has moved to  $\sim 50 R_J$ . Thus it should be possible to separate large scale spatial from temporal effects in the Jovian magnetosphere. It will also be possible to obtain measurements at four magnetic latitudes for each radial distance. Some of the key problems to be attacked are: (a) investigations of the variation of the radial position of the bow shock with time, and (b) the distortions of the magnetospheric boundary in response to fluctuations in the strength and direction of the solar wind and the rotation of the magnetosphere. An important feature of the Jovian magnetospheric observations possible with the TJSB mission is the simultaneous measurement of the solar wind outside the magnetosphere by one spacecraft while measurements within the magnetosphere are under way with the second spacecraft. (c) The nature of the "global" time dependent 10 hour variations of electron intensity and spectrum within the magnetosphere<sup>6, 9, 16</sup>; how is this effect related to the rotation effects of the equatorial plasma sheet and the spatially dependent 10 hour variation? This in turn is related to the problem of the mechanism for the release of electrons from Jupiter into interplanetary space. (d) Jovian satellite interactions with the trapped radiation; special opportunities exist whereby it is possible to cross the flux tubes associated with the satellite Io and thus to investigate the nature of the control exerted by Io over decametric radio bursts.<sup>6</sup>

In sum, the dual spacecraft out-of-the-ecliptic mission will answer questions which would otherwise remain a puzzle for studies made with a single spacecraft.

Observations made with Pioneer 10 and 11 have established the importance of transient phenomena<sup>6, 16</sup> for the magnetosphere of Jupiter, such as large scale distortions.

Observations with a single spacecraft cannot unambiguously separate the temporal and spatial dependences of such transient effects, so that a dual spacecraft mission offers our best hope for gaining a further understanding of the physics of the Jovian magnetosphere.

#### Phase (III): Out-of-the-ecliptic at large radial distances

Figure 4 illustrates the trajectory characteristics for spacecrafts A and B as a function of time after a Jovian swingby. In a period of  $\sim 2$  years, the two spacecrafts traveling in the opposite hemispheres of the interplanetary medium cover a radial distance of  $\sim 4$  a.u. while slowly traversing a solar latitude range of up to nearly  $90^\circ$ .

This phase of the mission offers the opportunity to take snapshots of solar active regions on the sun, (EUV, UV, x-rays, radio, etc.) for comparison with identical observations from Earth to form stereoscopic pictures of solar phenomena. It also becomes possible to investigate new aspects of the Gergenschein.<sup>2</sup>

This phase of the mission also offers the opportunity to study the behavior of magnetic sector structure at large radial distances from the Sun in the solar activity zone (Figure 1) to answer such questions as: (a) What role does the region of solar activity (10 to 35 degrees) play in determining the sector structure of magnetic fields extending from 1 to 5 a.u. ? (b) To what extent does the magnetic sector structure persist at high latitudes and at great distances from the Sun ? (c) How does the Sun's differential rotation, which produces a rotation period 9 days longer at the pole than at the equator, change the structure of interplanetary magnetic fields ? These and questions concerning the "global shape" of blast waves in the two hemispheres constitute major magnetic field and plasma studies for this phase of the mission. The characteristics of this region for charged particle propagation for both solar and galactic particles are entirely unknown, and their determination would be the prime goal of charged particle studies in this region.



Phase (IV): The polar observations at the Sun from  $\sim 1.2 - 2$  a. u.

A. Solar observations from the polar viewpoint.

The evolution of coronal features above solar active regions, coronal streamers and related transient, large scale phenomena -- now observable only by solar limb studies from Earth -- may be undertaken from the A or B spacecraft by time-lapse observations obtained simultaneously at all solar longitudes. Coronagraphic studies on a spinning spacecraft are difficult, but the potential is great for understanding the origin and dynamical structure of the inner and outer corona from simultaneous, polar and equatorial observations (J. A. Simpson to G. Newkirk, private communication, 1968).

B. Solar interplanetary studies.

Somewhere in the region tentatively identified as the transition region above solar latitude  $\sim 60^\circ$ , characteristics of the interplanetary medium increasingly become determined by the properties of the sun and corona in the polar regions. For example, it is currently believed that the polar region may be represented by a coronal hole where a continuous emission of the solar wind at high velocities ( $> 700$  km/sec) is expected.<sup>17</sup> It is in this region that the rotational effects of the Sun cease to play a major role in the large-scale structure of the magnetic field carried into interplanetary space by the solar wind. The properties of this region are unknown and expected to be totally different from those so far studied in the vicinity of the equatorial plane. For studies in this region it is vital that measurements in the north and south polar regions be made simultaneously since it is well-established that both the temporal and spatial distributions of observable solar phenomena in the polar regions are frequently different at the two poles.<sup>18</sup> In addition to the particle, magnetic field and plasma interactions which will be studied for the first time under these new physical conditions, we point out that

low energy particles from the galaxy may find a relatively easy entry to this

region, as discussed below.

As shown in Figure 4, the two spacecrafts pass from pole to pole in periods the order of 260 days (or on an average of  $\sim 0.7^\circ$  per day). This corresponds to an elapsed time of  $\sim 10$  solar rotations when the two spacecrafts are at radial distances  $\sim 1.2$  to  $1.5$  a.u. Clearly radially dependent effects are likely to be small compared with latitudinally dependent phenomena being studied simultaneously on the two spacecraft. The observations to be made and the scientific objectives of Phase IV of the dual spacecraft are essentially the same as those for the SEP mission (options 9 and 10). Both missions provide a scan of solar latitude at a rate of  $\sim 0.4 - 0.7$  degrees per day at approximately constant radial distance from the Sun, although the dual spacecraft mission provides coverage of the polar region of the Sun, while the SEP mission does not. Among the latitude dependent phenomena to be investigated are (a) the effect of differential rotation on the magnetic field structure in interplanetary space; (b) the nature of the transition region from the polar coronal holes to the band of solar activity (Figure 1); (c) the nature of transient phenomena such as shocks and high velocity streams at high solar latitudes. Measurements relating to these questions made in Phase IV are distinguished from similar measurements in Phase III by the fact that the radial position of the spacecrafts is not an important parameter during Phase IV, thus providing a clean separation of latitudinal and radial effects.

It is likely that the combined direct solar observations, magnetic field, plasma and high energy particle studies will introduce a qualitative change in our understanding of the differential rotation of the Sun, of the  $\sim 22$  year magnetic cycle and, thereby, in our understanding of the internal dynamics of the Sun.

#### C. Galactic composition of cosmic radiation.

In part B above, measurements during the pole-to-pole excursion of the

two spacecrafts were concentrated on the electrodynamics of the interplanetary medium and the role of the solar features in determining the dynamics of the medium. If conditions over the solar poles are anywhere near those predicted it would appear that cosmic ray particles of low energy from the galaxy which cannot otherwise propagate into the inner part of the solar system near the equatorial plane because of solar modulation may be able to penetrate by way of the solar polar magnetic fields to within  $\sim 1 - 2$  a. u. If so, we may be able to obtain for the first time samples of the low energy composition of galactic cosmic rays; that is, the relative abundances of the elements in the nuclear component of the cosmic rays and the relative isotopic abundances of hydrogen to nickel. Through such studies it may become possible to identify the low energy component of cosmic rays accelerated in our local region of the galactic arm. These studies will be of vital importance for deciding among models of nucleosynthesis of the elements in the sources of cosmic rays. Furthermore, under such circumstances, it would become possible to obtain the energy densities in interstellar space for these very low energy particles (a problem concerned with the heating of interstellar clouds).

Finally, all of these investigations over the solar pole when taken together with observations in the equatorial plane will yield a "global" model for solar modulation which takes account of the propagation of nuclear particles and electrons extending downward in energy to energies where at present their modulation is not understood. Recent observations<sup>19, 20</sup> show that even at higher energies, revisions of our ideas about modulation may be required, possibly involving processes taking place off the ecliptic plane<sup>21</sup>, or introducing interstellar neutral particles in the heliosphere.<sup>22</sup> The IMP satellites and Pioneer 10/11 deep space probe observations have raised a number of interesting questions regarding whether or not low energy particles could have access to the solar equatorial zone.

#### D. Energetic particles of solar origin.

The role of coronal transport in the propagation of solar particles from flare sites to the interplanetary medium has been much studied but is not well understood.<sup>23-26</sup> Out-of-the-ecliptic missions will play a major role in deciding on the transport mechanism, on the storage time and distribution of particles at the sun, and, in turn, while using solar particles as probes of the intervening magnetic fields, will obtain information on the near-sun magnetic field structure including the distribution of irregularities in the magnetic field. It may be possible that the effects of differential rotation can be analyzed best by studying the emission of solar flare particles at high solar latitudes.

#### E. Models of the heliosphere.

At the present time we cannot choose conclusively among models of the heliosphere with boundaries for particle modulation which, for example, could be a) pancake-like in character, extending the order of say 20 to 50 a.u. in the equatorial region, but only a few astronomical units thick over the poles, or b) with distant boundaries over the solar poles and therefore much more spherical in character, as sketched in Figure 7.<sup>27</sup> Although these two examples represent extremes, it would appear that data obtained out-of-the-ecliptic plane could assist in deciding between them by using galactic cosmic rays as probes of the outer magnetic fields of the interplanetary medium. Predictions for the charged particle gradients, particle anisotropies and energy spectral changes as a function of solar latitude can be made; therefore a wide range of models can be tested by the dual spacecraft mission (e.g. reference 28).

#### Phase (V): Post solar polar observations

The above four phases of the dual mission illustrate the wide range of physical processes which can be studied during the mission. After leaving the sun the dual spacecrafts again travel outward from the Sun where they are able to repeat some of the observations which were obtained between Jupiter and the Sun in Phase III as much as a half solar cycle earlier.

These latter measurements would indeed be very interesting since they can provide further evidence on the long-term changes in the heliosphere, especially in the latitudinal structure of the interplanetary magnetic fields.

#### IV. Summary Remarks

We conclude from the mission alternatives that the latitude scan missions such as the SEP options 9 and 10 (Figure 2) are dedicated to more detailed observations and exploration of the solar active zones (Figure 1) with a strong emphasis on extending the stereoscopic viewing of the solar phenomena now under observation with Earth orbiting satellites. On the other hand, the solar polar cap passes further extend the exploration of new regions of the Sun and interplanetary medium, the evolution of solar coronal features seen simultaneously at all solar longitudes, and the possible access of low energy particles from interstellar space via the polar magnetic fields. Such particles can not be detected with deep space probe missions near the equatorial plane in the foreseeable future. Thus, in many aspects both types of missions are important for science, but are qualitatively different in their goals.

With regard to strategies, the TJSB missions offer the unique advantage of providing well-defined interfaces for international collaborations since one spacecraft could, for example, be the responsibility of the European Space Agency while the second spacecraft could be the responsibility of the NASA.

Some instruments should cover the same measurements simultaneously on both spacecrafts, e. g. magnetic fields, plasmas, charged particles and x-rays. However, in addition one spacecraft could carry a set of complex instruments to complement the other spacecraft, viz. a coronagraph on one spacecraft, and a complex super-thermal particle spectrometer and solar radio emission detector on the other spacecraft.

Although Table 1 suggests a wide range in costs based upon the launch vehicle, the ultimate difference between a single spacecraft JSB mission and TJSB mission is really less than indicated because the same magnitude of commitment and resources is required for scientific instrument preparation and integration, for data acquisition throughout the years of the mission and, most important, for the level of commitment of those in the scientific community motivated to undertake such a long term enterprise.

The need for simultaneous measurements at Earth during an exocliptic mission must not be overlooked in order to separate spatial from temporal changes in solar interplanetary phenomena, and to relate these observations to the present day scientific knowledge derived from equatorial measurements.

Ingenious experiments and observations have been reported for many years to explore the high solar latitudes near the Sun and interplanetary space. These include the use of radio waves from distant stars to study the magnetic irregularities and electron densities near the Sun, the observation of comet tails at high latitudes and the scintillation effects of galactic cosmic rays to deduce properties of the solar wind, and the large-scale probing of the interplanetary medium by high energy cosmic rays to estimate the scale size of the heliosphere. However, they cannot substitute for direct observations in the regions of the solar system to be penetrated by an exocliptic mission.

The author apologizes for not adequately covering in this note the many alternate mission options with their unique scientific objectives.

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**Table 1**  
**SOLAR EXECLPTIC MISSION OPTIONS FOR THE EARLY 1980's**

Option	Flight Mode <sup>f</sup>	Launch Vehicle	No. of Space-craft	Total S/C (Science*) Mass, KG	Max. Solar Lat., Deg. <sup>g</sup>	Spin (SP) or Stable (ST) S/C	Launch Year(s)	Time to Max. Lat., Years	Heliographic Coverage	Cost Bracket <sup>d</sup>
(1)	JSB	Shuttle/IUS(3)/TE 364	2	550(60)	84	SP	1981, 83	3.9	Opposed passes, ± latitude scans	Med-Hi
(2)	JSB	Titan/Cent/-45 <sup>a, b</sup>	2	500(60)	90/90	SP	1980, 81, 83	~4	Opposed single passes ± latitude scans	Hi
(3)	JSB	Shuttle/IUS(2)/TE 364	1	300(30)	88	SP	1981, 83	3.9	Single pass to ± 88°	Lo-Med
(4)	JSB	Atlas/Cent/-45 <sup>b</sup>	1	250(30)	39	SP	1980	~4	Single pass	Med
			1	150(15)	77	SP	1980	~4	Single pass	Lo-Med
(5)	JSB	Delta 3914/★27 <sup>c</sup>	1	150(15)	~30	SP	1981, 83	~4	Single pass	Lo
(6)	ΔVEGA + JSB	Atlas/Centaur/TE 364	1	300(30)	79	SP	1982	5.6	Single pass to ± 79°	Med
(7)	DB	Titan/Cent/-45 <sup>a, b</sup>	1	250(30)	34	SP	1980-83	~0.2	Single lat. scan ~ 1 a.u.	Med-Hi
			1	150(15)	37	SP	1980-83	~0.2	Single lat. scan ~ 1 a.u.	Med
(8)	DB	Delta 3914/★27 <sup>c</sup>	1	150(15)	24	SP	1980-83	~0.2	Single lat. scan	Lo
(9)	DSLP (15KW)	Titan/Centaur <sup>a</sup>	1	250(30)	59	ST	1981, 82, 83	~2.7	Latitude scans ~ 1 a.u.	Hi
			1	150(15)	62	ST	1981, 82, 83	~2.7	Latitude scans ~ 1 a.u.	Hi
(10)	DSEP (6KW)	Atlas/Centaur <sup>a</sup>	1	250(30)	29	ST	1981, 82, 83	~2.2	Latitude scans ~ 1 a.u.	Med-Hi
			1	150(15)	34	ST	1981, 82, 83	~2.2	Latitude scans ~ 1 a.u.	Med

a. This vehicle or shuttle/IUS (interim upper stage) equivalent for ≥ 1981 launches.

b. -45: TE 364-4 solid kick motor with spin table.

c. ★27: Star 27 solid kick motor

d. Cost bracket determined on basis of launch vehicles shown, not shuttle equivalents (see footnote a).

\* Science included in spacecraft masses.

†† Latitudes: Latitudes are heliographic. Hence when tandem spacecraft are launched to solar latitudes less than 90°, one S/C goes below the ecliptic and the other above after swingby, with ~ 14° difference in solar latitude if the swingby is at the solar node.

‡ Flight Modes: JSB - Jupiter Swingby  
VEGA- ΔV - Earth Gravity Assist  
DB - Direct Ballistic  
DSEP - Direct Solar Electric Propulsion

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### Figure Captions

**Figure 1** Idealized meridional plane view of the interplanetary regions associated with principal features on the sun. The shaded region represents a region  $\pm 7^\circ$  in solar latitude within which all measurements to date have been made. The region of principal solar activity over a solar cycle extends from 10 to  $\sim 35$ -40 degrees north and south latitudes and is highly variable. A region from  $\sim 40$  to 70 degrees is a transition region between the region of solar activity and the polar region where the rotational effects on the magnetic field carried out by the solar wind begin to subside. It is believed that the polar region is mainly occupied by a coronal hole-like structure and therefore that the solar wind has a high velocity in this region.

**Figure 2** The solar electric propulsion mission is one in which the spacecraft remains in a 1 A. U. orbit from the sun and is therefore synchronous with earth. The orbit inclination is increased by thrusting about the nodes. In a period of  $\sim 3 \frac{1}{2}$  to 4 years a full excursion of the spacecraft is expected to be between 50 and 60 degrees. The spacecraft is normally thrusting except for  $\sim 100$  days per year at the anti-nodes. However, the spacecraft propulsion can be turned off for a day or so during the normal operating periods to obtain scientific data. (See references 4 and 5.)

**Figure 3** The  $\Delta$ VEGA flight mode ( $\Delta$ V-Earth Gravity Assist). In this mode the transfer event points are:

Point 1: Earth launch 4/18/82,  $C_3 = 27 \text{ Km}^2\text{-sec}^{-2}$ .

Point 2: Perihelion modification maneuver,  $\Delta V = 900 \text{ m-sec}^{-1}$ .

Point 3: Earth powered swingby,  $\Delta V = 1000 \text{ m-sec}^{-1}$ .

Point 4: Jupiter encounter 3.2 years after launch.

The trajectory is not to scale.

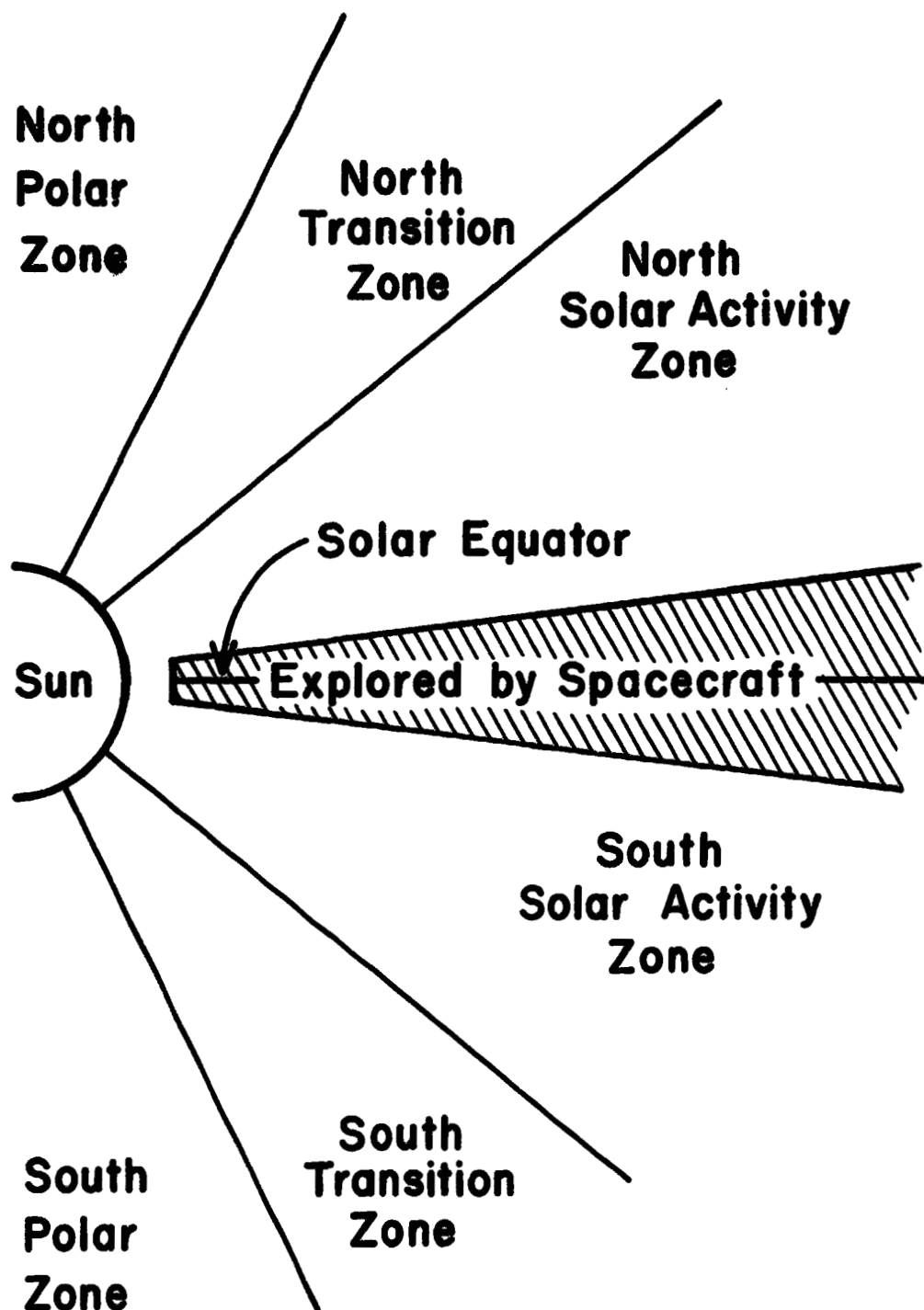
**Figure 4** The out-of-the-ecliptic trajectory for the dual mission after Jupiter swingby, showing the radial distance of the spacecrafts from the sun and the heliographic latitude of each spacecraft as a function of time. (Adapted from reference 7.)

**Figure 5** The dual spacecrafts A and B enter the Jovian magnetosphere approximately 2 or 3 days apart. The figure is a meridional projection of the spacecraft trajectory with Jupiter at the center of the coordinate system. The fiducial marks on trajectory A represent 6 hour intervals which correspond in numbers to the 6 hour intervals along trajectory B. Thus it is seen that one spacecraft is near closest approach when the other spacecraft is at 50 Jovian radii.

The trajectory of Pioneer 11 is shown for comparison.

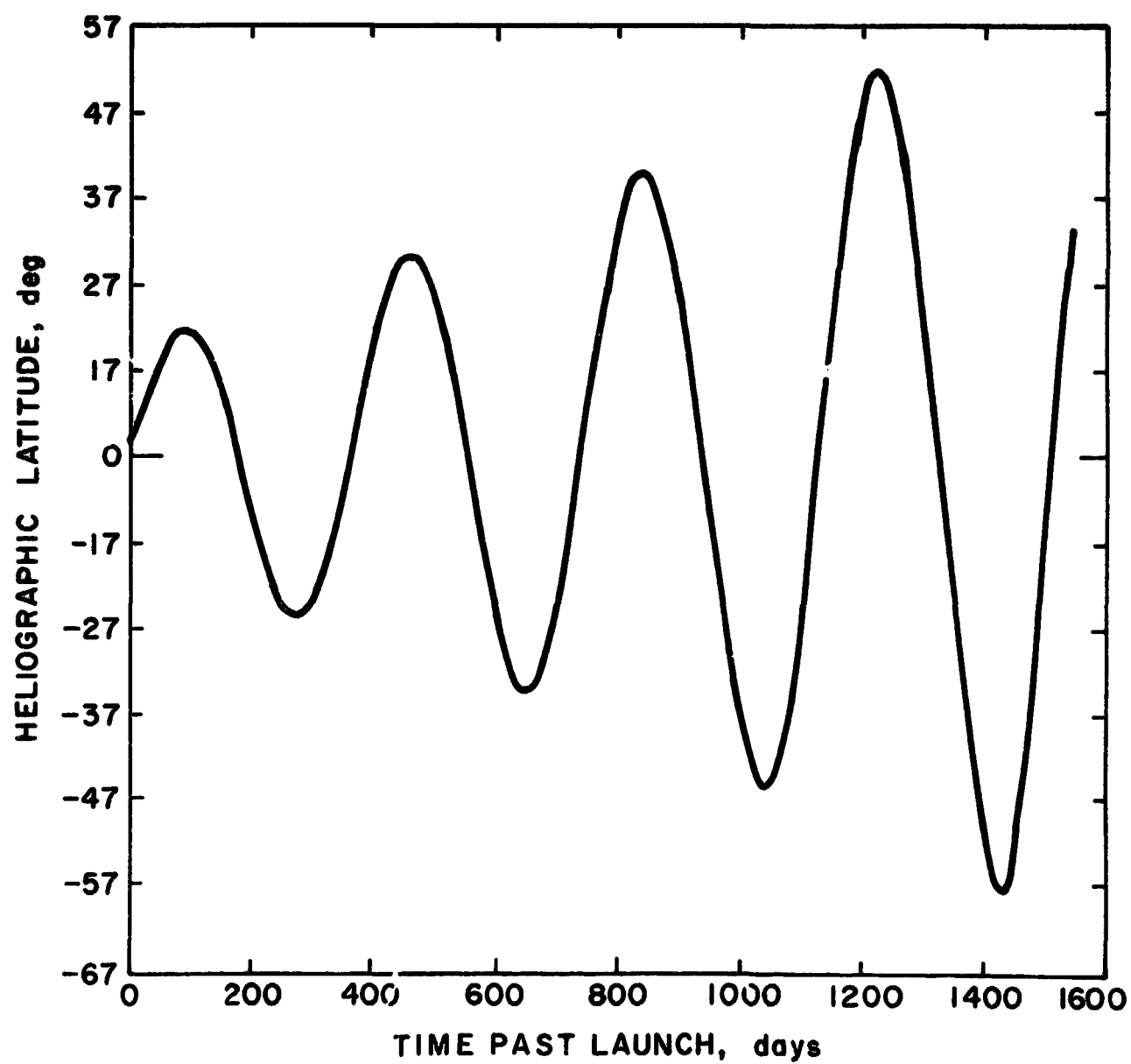
**Figure 6** Projection on the ecliptic plane of the trajectories of spacecraft A and spacecraft B. For comparison the trajectory of Pioneer 11 is shown.

**Figure 7** Two alternate models for the shape of the heliosphere. (See reference 27.)



**Idealized Meridional Diagram of Solar Regions  
Connecting with the Interplanetary Medium**

## HELIOGRAPHIC LATITUDE PROFILE



(From J.P.L. Report by J.H. Duxbury, 9/26/74)

Figure 2

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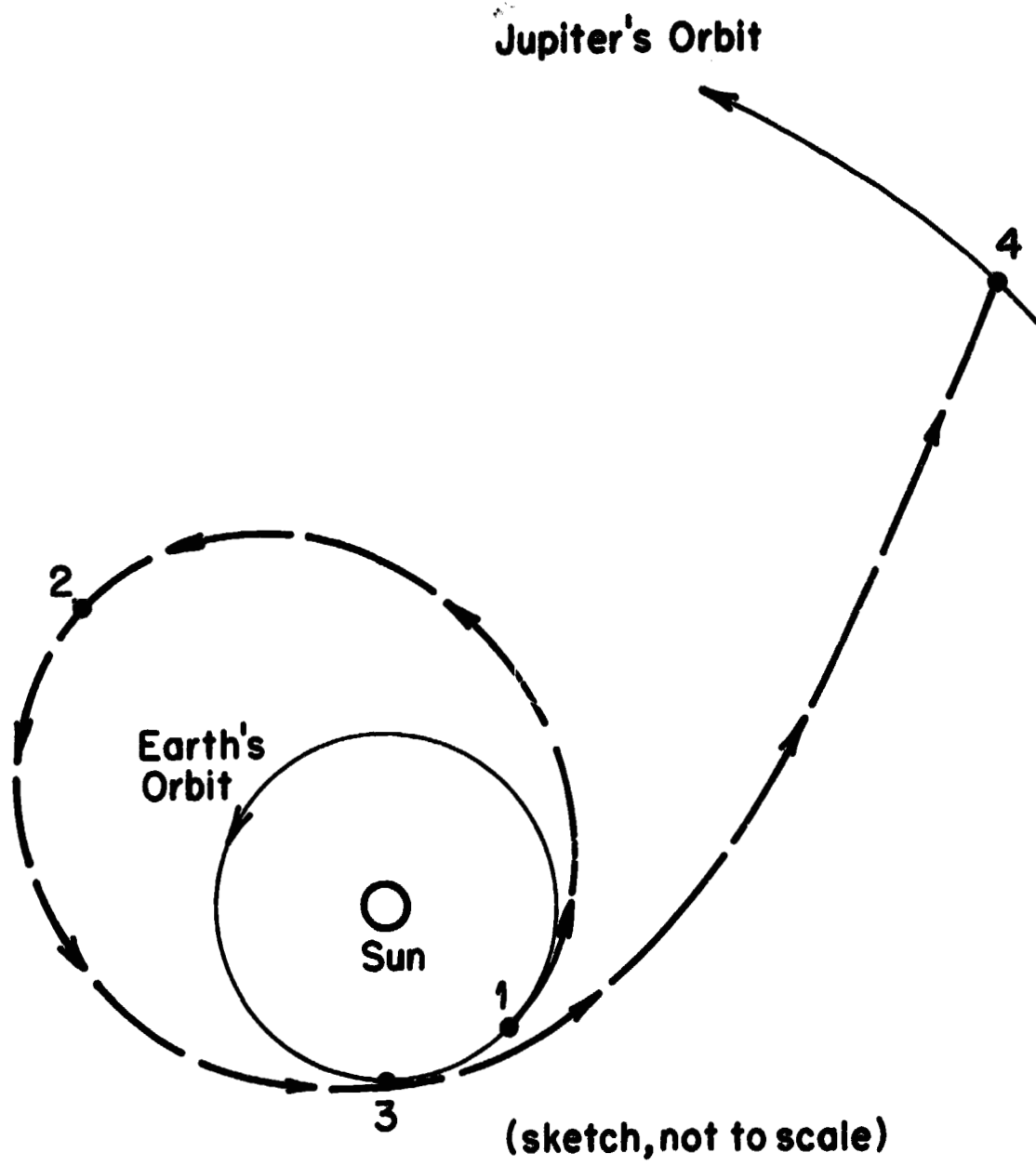
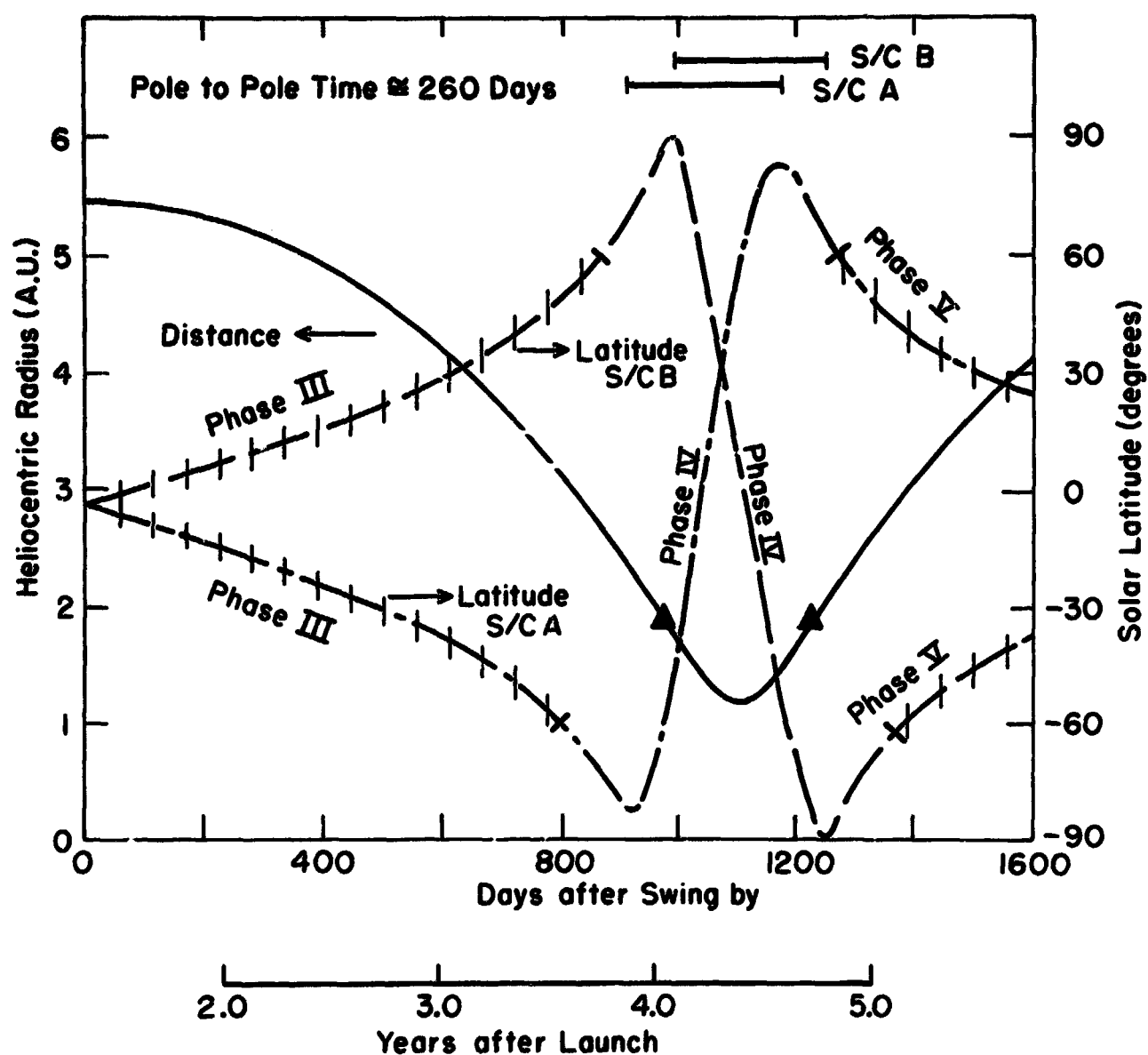


Figure 3

**Out of Ecliptic Trajectory, Heliographic Distance and Latitude  
Dual Pioneer Spacecraft, Single Titan 3E/Centaur/TE 364-4**



(adapted from Figure by H.F. Matthews, NASA/ARC)

Figure 4



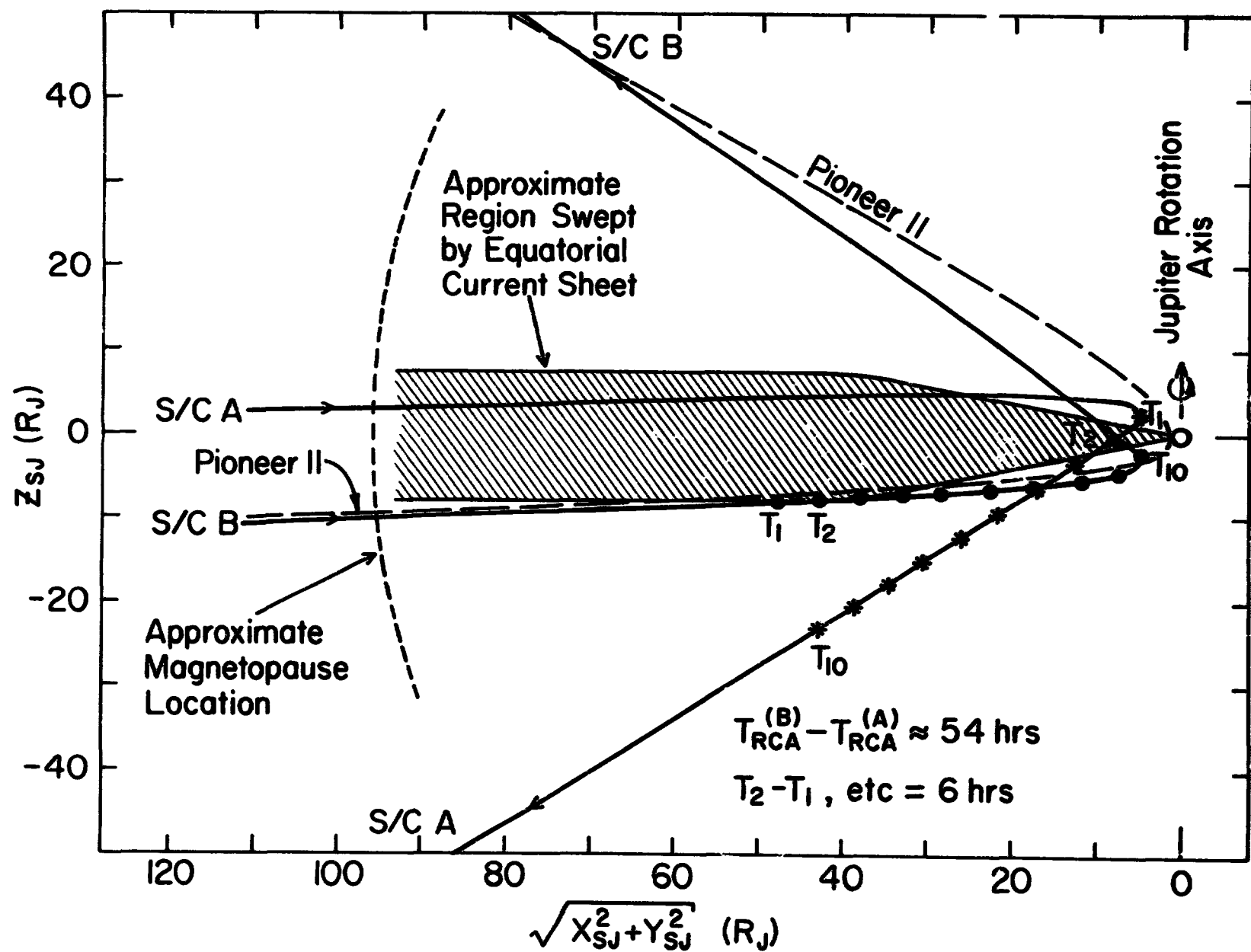


Figure 5

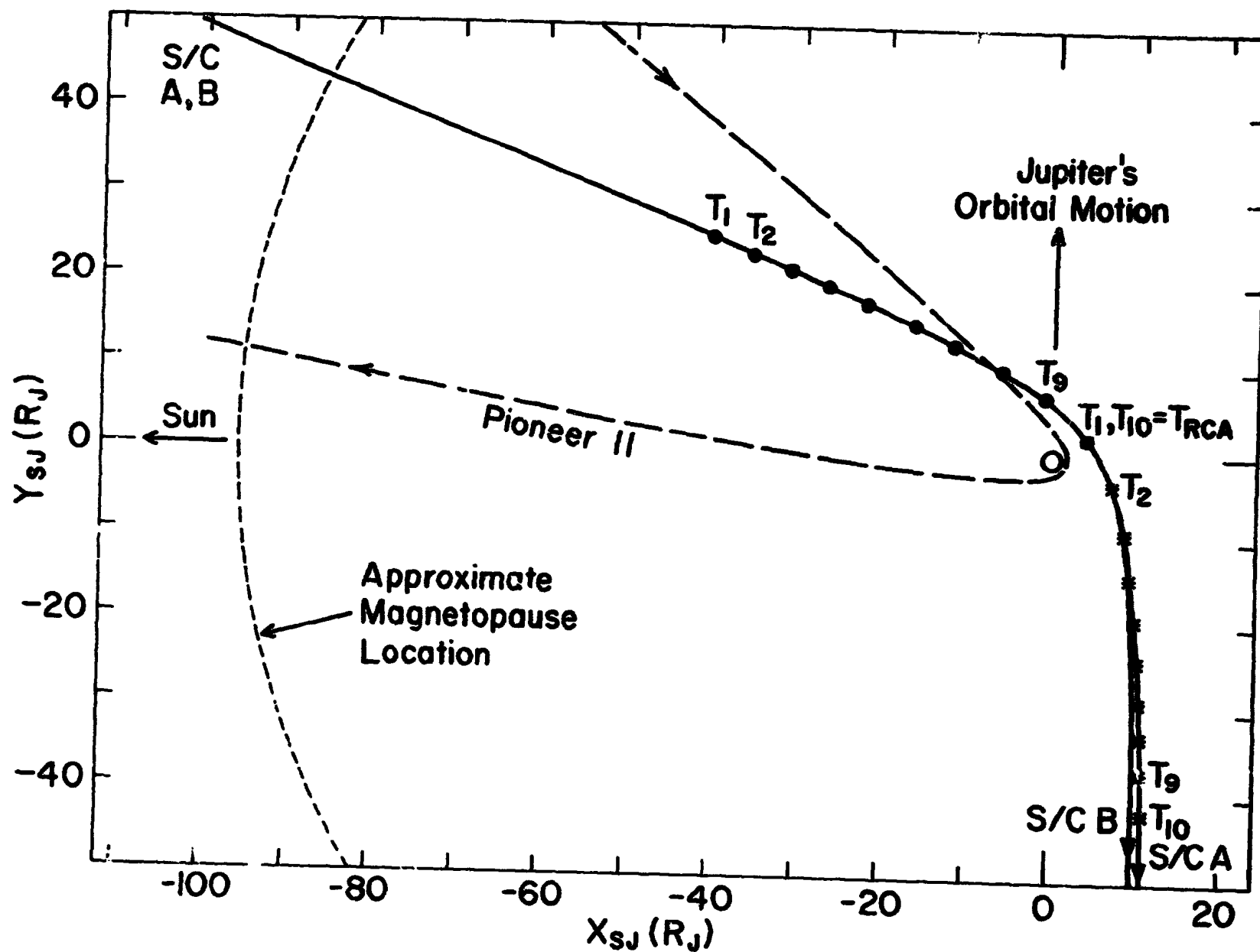


Figure 6

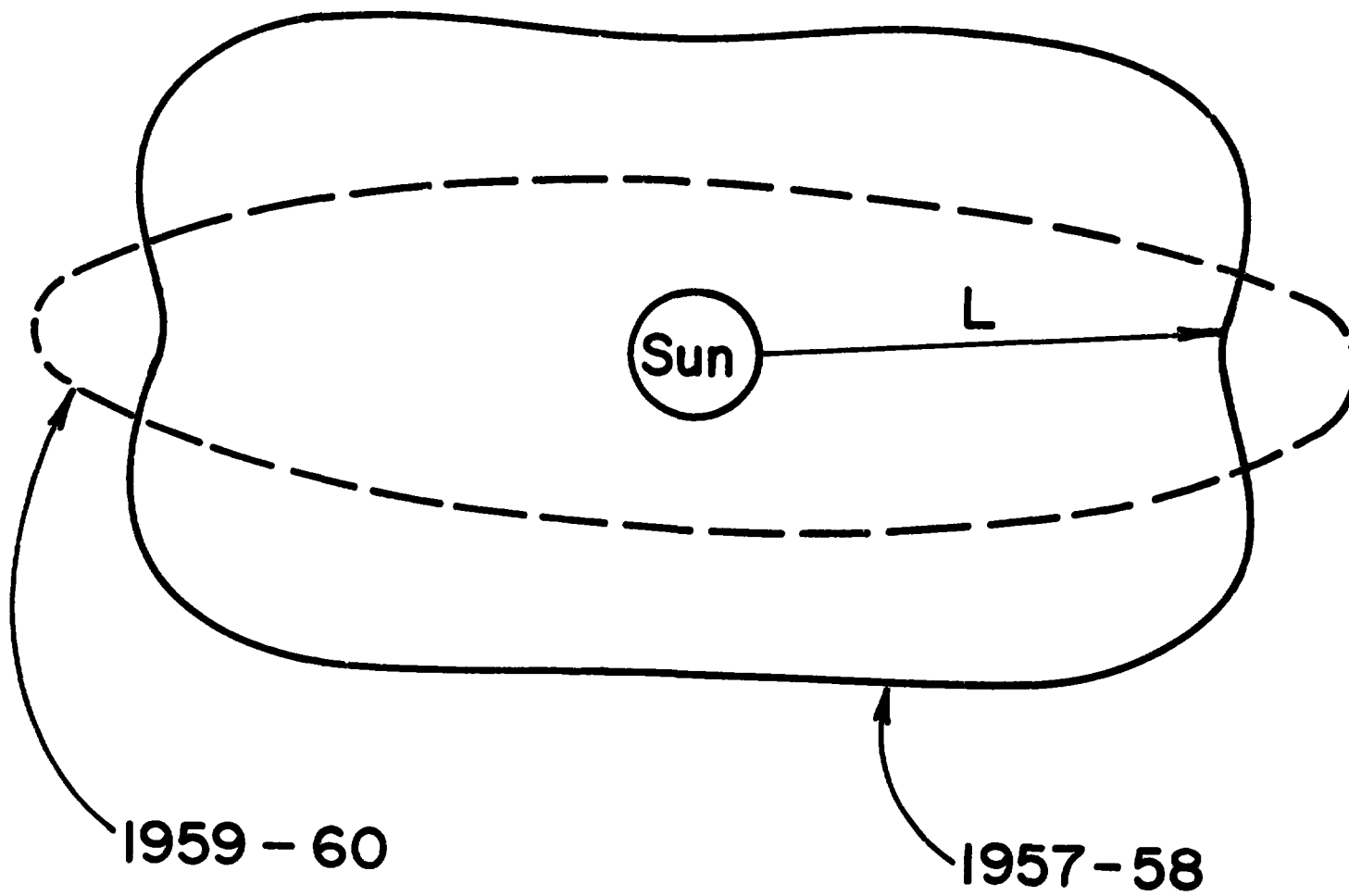


Figure 7